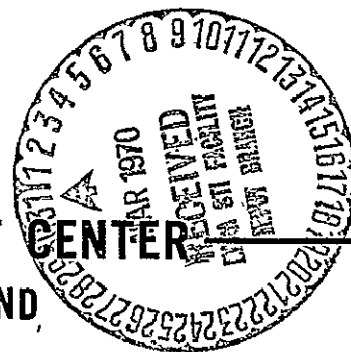# A GUIDE TO THE LITERATURE
ON CARBON DIOXIDE LASERS
(1 JULY 1968 - 30 JUNE 1969)

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GSFC —— GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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CONTENTS

ABSTRACT

This document presents the results of a literature search on carbon dioxide lasers through thirty-one scientific and technical journals and the NASA Scientific and Technical Aerospace Reports (STAR) for the period 1 July 1968 through 30 June 1969. The results are presented in a chronological listing in which each item contains three sections: (1) a standard bibliographical listing, (2) an abstract of the paper or article, and (3) a comprehensive listing of keywords or phrases extracted from the publication. Over 122 references by 220 authors are included. This listing is followed by an alphabetical listing of the authors with their publications referenced to their chronological order number. The third listing, consisting of 356 items, gives, in alphabetical order, the extracted keywords and phrases referenced to the articles by the chronological reference number. This document will reduce considerably the time required to search the literature on carbon dioxide lasers or to find the value of a particular parameter of the laser.

A GUIDE TO THE LITERATURE ON CARBON DIOXIDE LASERS
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1. INTRODUCTION

The remarkable growth of the carbon dioxide laser has continued without evidence of slackening during the period covered by this guide. This and the previous document* give clear evidence of this growth, since one of the most reliable indicators is the number of publications which have appeared relating to the carbon dioxide laser. A quick glance at incomplete yearly totals (incomplete because no search can include every scientific and technical journal, magazine, and report written) shows that 8 publications appeared in 1964, 9 in 1965, 33 in 1966, 55 in 1967, 83 in 1968, and 57 in the first half of 1969.

The following document consists of four sections: (1) A bibliography of review material – publications giving a broad view of the carbon dioxide laser. (2) An annotated chronological listing of the articles on the carbon dioxide laser which have appeared in thirty-one scientific or technical journals during the period 1 July 1968 through 30 June 1969. This listing includes the standard bibliographic item, an abstract of the article (usually the author's abstract, when it is available), and a number of keywords or phrases extracted from the article which describe its contents. Each of the articles is numbered and the assigned number is used in the remainder of this document to identify the article in question. In addition to journal articles, an effort was made to survey the federal government's unclassified efforts in this area. The National Aeronautics and Space Administration publishes a semimonthly abstract journal entitled <u>Scientific and Technical Aerospace Reports</u> (STAR) which includes a comprehensive coverage of scientific and technical reports published by NASA and its contractors, as well as scientific and technical reports of other government agencies, universities, and research organizations throughout the world. All work mentioned in this journal during the period in question has been included in this document. (3) An alphabetical listing of all authors with a listing of the reference numbers of their publications. (4) An alphabetical index of the keywords and phrases which characterize the various publications and which were extracted in the second section. It is hoped that a researcher or engineer will be able to materially shorten the time required for him to locate the references giving a particular parameter, construction technique, or design approach by using this report.

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*See reference number 55 in this document

The following journals were searched in the preparation of this document.

1. American Journal of Physics
2. Applied Optics
3. Applied Physics Letters
4. Bell System Technical Journal
5. Comptès Rendus, Academie des Sciences, Paris
6. Electronic Engineering
7. Fujitsu Scientific and Technical Journal
8. Indian Journal of Applied Physics
9. Infrared Physics
10. IEEE Journal of Quantum Electronics
11. IEEE Transactions on Antennas and Propagation
12. IEEE Transactions on Electron Devices
13. Japanese Journal of Applied Physics
14. Journal of Applied Physics
15. JETP – Letters
16. Journal of Molecular Spectroscopy
17. Journal of the Optical Society of America
18. Journal of the Physical Society of Japan
19. L'Onde Electrique
20. Philips Research Reports
21. Philips Research Reports Supplements
22. Philips Technical Review
23. Physica
24. Physical Review
25. Physical Review Letters
26. Physics Letters
27. Proceedings of the IEEE
28. Proceedings of the Royal Society

29. Soviet Physics – JETP

30. Soviet Physics – Technical Physics

31. Soviet Physics – Uspekhi

A number of omissions were unavoidable if a timely production of this report were to occur. The following journal issues were not searched: Soviet Physics – JETP – June 1969, Soviet Physics – Uspekhi – Mar. – Apr. 1969 and May – June 1969, Philips Technical Review – Vol. 30 No. 6, Philips Research Reports – Vol. 24 No. 3, and Philips Research Reports Supplements – No. 5 and No. 6 1969.

The following issues of Scientific and Technical Aerospace Reports (STAR) were searched: N68-23 045, Vol. 6, No. 13, 8 July 1968 through N69-24 750, Vol. 7, No. 12, 23 June 1969.

It was elected not to continue the search into journals in languages other than English since most of the significant work has been reported in English and that which has been published in other languages can often be obtained second-hand from articles written in English. The restriction was imposed because of the practical limitations on the time and effort which could be devoted to this task. Unfortunately, such a restriction must slight the work of a number of highly competent researchers. The French performed some of the earliest work on the carbon dioxide laser and have continued to perform significant, important work; this has not been thoroughly searched or acknowledged. Twelve of the more important articles which may be useful to the researcher or engineer are:

Borde, C., Henry, A., and Henry, L.: Emission du gaz ammoniac excite par le rayonnement d'un laser a gaz carbonique. Comptes Rendus, Academie des Sciences, Paris, Vol. 262, No. 21, May 23, 1966, pp. 1389–1390.

Borde, C.. Henry, A., and Henry, L.: Comportement de differents gaz soumis au rayonnement d'un laser a gaz carbonique. Comptes Rendus, Academie des Sciences, Paris, Vol. 263, No. 9, August 29, 1966, pp. 619–620.

Brunet, H.: Excitation vibrationnelle de l'hexafluorure de soufre par l'absorption d'un rayonnement laser. Comptes Rendus, Academie des Sciences, Paris, Vol. 264, No. 25, June 19, 1967, pp. 1721–1723.

Van Lerberghe, A., Arya, G., Margott-Maclou, M., and Henry, L.: Etude du temps de recouvrement du laser a gaz carbonique excite par decharges impulsionnelles. Comptes Rendus, Academie des Sciences, Paris, Vol. 265, No. 6, August 7, 1967, pp. 359–362.

Jerphagon, J., Batifol, E., Tsoucaris, G., and Sourbe, M.: Generation de second harmoniqu dans le cinabre. Comptes Rendus, Academie des Sciences, Paris, Vol. 265, No. 8, August 21, 1967, pp. 495-497.

Brunet, H. and Perez, M.: Absorption saturable de SF_6 a 10.59μ. Comptes Rendus, Academie des Sciences, Paris, Vol. 267, No. 20, November 13, ·1968, pp. 1084-1086.

Borde, C., and Henry, L.: Stabilisation d'un laser a gaz carbonique et observation du phenomene de "Lamb dip" pour les transitions laser vers 10μ. Comptes Rendus, Academie des Sciences, Paris, Vol. 265, No. 22, November 27, 1967, pp. 1251-1254.

Leiba, E.: Heterodynage optique avec un detecteur pyroelectrique. Comptes Rendus, Academie des Sciences, Paris, Vol. 268, No. 1, January 6, 1969, pp. 31-33.

Lemaire, J., Houriez, J., Bellet, J., and Thibault, J.: Double irradiation par rayonnements infrarouge et hertzien. Comptes Rendus, Academie des Sciences, Paris, Vol. 268, No. 13, March 31, 1969, pp. 922-925.

Huetz-Aubert, M. and Chevalier, P.: Relations entre les temps de relaxation thermiques de vibration de termines par differentes methodes. Application au melange CO_2-N_2. Comptes Rendus, Academie des Sciences, Paris, Vol. 268, No. 14, April 9, 1969, pp. 965-968.

Huetz-Aubert, M. and Chevalier, P.: Relations entre les temps de relaxation thermiques de vibration, determines par les methodes de point d'arret, de fluorescence et du spectrophone. Confrontation des expressions theoriques avec les resultats experimentaux obtenus pour CO_2 pur et pour le melange CO_2-N_2. Comptes Rendus, Academie des Sciences, Paris, Vol. 268, No. 16, April 21, 1969, pp. 1068-1071.

Lavarini, B., Brunet, H., Frapard, C., Laures, P., Michon, M., and Neubauer, M.: Laser moleculaire continu CO_2-N_2He de grande densite de puissance. Comptes Rendus, Academie des Sciences, Paris, Vol. 268, No. 23, June 9, 1969, pp. 1504-1506.

It is almost inevitable that omissions or errors have crept into this work. The compilers regret all mistakes and earnestly seek corrections and additions so that this listing may be as accurate as possible. Suggestions and comments can be sent to the Optical Systems Branch, Mail Code 524, Goddard Space Flight Center, Greenbelt, Maryland, 20771.

2. REVIEW MATERIALS

A chronological listing of review articles relating in total or in part to the carbon dioxide laser follows. In some cases these are repeated in the following section when they appear in journals covered in the search.

Peppers, N. A., Vassiliadis, A., Dedrick, K. G., Chang, H. H. C., Peabody, R. R., Rose, H., and Zweng, H. C.: Corneal Damage Thresholds for CO_2 Laser Radiation. Applied Optics, Vol. 8, No. 2, February 1969, pp. 377-381.

Wyman, P. W.: Laser Radar Eye Hazard Considerations. Applied Optics, Vol. 8, No. 2, February 1969, pp. 383-392.

Chang, H. H. C. and Dedrick, K. G.: On Corneal Damage Thresholds for CO_2 Laser Radiation. Applied Optics, Vol. 8, No. 4, April 1969, pp. 826-827.

Kikuchi, B., Nakayama, N., Misugi, T., Yamaoka, T., and Ueda, Y.: CO_2 Gas Laser. Fujitsu Scientific and Technical Journal, Vol. 5, No. 2, June 1969, pp. 117-137.

3. ANNOTATED CHRONOLOGICAL BIBLIOGRAPHY

The following bibliography lists the papers pertaining to the carbon dioxide laser in chronological order. Each paper has been assigned a reference number in accordance with its chronological position. These numbers are employed in the index to identify the papers.

1. Mocker, H. W.: Carbon Dioxide Laser Progress Report, July 1, 1967 – Sept. 15, 1967, Honeywell, Inc., St. Paul, Minns, Oct. 1, 1967. Contract NAS 8-20645. Avail.: CFSTI, CSCL20E.

   Abstract: The shift of the frequency of oscillation of the $00°1$ to $10°0$ rotation-vibration band at 10.6 micrometers of a CO_2 laser was investigated as a function of total pressure, CO_2-partial pressure, discharge current, and cavity mode position. The measurements were made by heterodyning two passively stabilized CO_2 lasers, both oscillating in a single transverse mode and single frequency at the P-branch of the $00°1$ to $10°0$ rotation-vibration band of CO_2. The result yielded a 5 to 8 MHz/ Torr frequency shift towards red due to an increase in total pressure and a 500 to 900 KHz/ma shift toward blue due to an increase in excitation. The amount of frequency shift due to excitation was found to be independent of the location of the cavity resonance with respect to the Doppler center. The dependence on CO_2 partial pressure was also determined.

   Keywords: Heterodyne Detection, Frequency Shift due to Pressure Variations, Frequency Shift due to Current Variations, Stability (passive)

2. Reynolds, R. S.: Stabilized Carbon Dioxide Gas Laser. Final Report, Sylvania Electric Products, Inc., December 1, 1966 – January 30, 1968. Contract NAS 5-10309.

   Abstract: A CO_2 laser capable of high power at a single frequency, highly stabilized on the short term is presented. This laser has been developed for use in long range communications systems. The laser utilizes a master-oscillator, power-amplifier to achieve high power simultaneously with high stability and is capable of providing up to 38 watts of single-frequency light in the TEM_{00q} mode. A temperature-controlled oscillator provides 5 watts of power at a single wavelength at 10.6 micrometers from an active plasma length of 40 cm. A second oscillator was used to obtain relative frequency stability information by heterodyne techniques. Long-term stability was determined by the thermal environment and was about ±3 parts in 10^7. The short-term stability varied between 5 parts in 10^{11} and 1 part in 10^9 over

a 10 ms time interval. The short-term frequency stability depends strongly on the laser acoustical environment. Experimental results are also presented on the effects of RF excitation, laser bore size, and gas mixture on the laser output.

Keywords: High Power Output, Frequency Stability, Parameter Study, RF Excitation, Master-Oscillator - Power-Amplifier

3. Taylor, F. M., Lombardo, A., Eppes, W. C.: Effect of a Heated Platinum Wire on a Sealed Carbon Dioxide laser System. AF Avionics Laboratory, Wright-Patterson AFB, Ohio, Contract F33615-67-C-1138, April 1968.

Abstract: A heated platinum wire was used in a sealed CO_2-N_2-He laser system, resulting in increases in output power that were dependent on the initial fill pressure of CO_2. The system was also filled with a CO_2-He mixture and made to lase. Heating of the platinum wire caused a decrease in output power. It was tentatively concluded that the platinum catalyzes the reaction CO + O to CO_2 permitting a higher concentration of CO_2 in a sealed system than is otherwise possible.

Keywords: Heated Platinum Wire, Sealed System

4. Bokhan, P. A. and Egorova, E. S.: The Feasibility of Increasing Output Power from a CO_2-N_2-He Mixture. Air Force Systems Command, Wright-Patterson AFB, Ohio, April 1968, AD 681579, FTD-HT-23-252-68. Avail.: CFSTI CSCL 20/5.

Abstract: The achievement of higher output power in CO_2 lasers with large-diameter discharge tubes is hampered by a tendency toward a pinch effect and ineffective cooling of the gas. An attempt to overcome these problems was made with non-contracting discharge using a water-cooled discharge tube 70 mm in diameter and a discharge gap 150 cm long. Maximum input power was 2200 watts. The output was 95 watts at an efficiency of 4.3% and a wavelength of 943 cm^{-1}. The thermal source density was constant over the tube cross section, and the wall temperature was 0°C. At 2200 watts input with He, the axial temperature rose to 280°C. In view of the nonlinear input-temperature curve, an axial temperature of 500°C. in the presence of He requires a nearly doubled tube diameter which quadruples the output power obtained from a 1 meter length of the tube. Considering that cooling and emission extraction can be further improved, and also that water vapor can be introduced into the discharge, a power output per meter of 300-400 watts is possible.

Keywords: High Power Output, Additive (water vapor), Large Diameter Tube, Efficiency, Discharge Pinch Effect, Pinch Effect

5. Gordiyets, B. F., Sobolev, N. N., and Shelepin, L. A.: Kinetics of Physical Processes in a CO_2 Laser. NASA TT-F-11667, May, 1968.

Abstract: A method is developed for calculating the populations of the vibrational levels of a CO_2 laser. The vibrational and the gas temperatures are determined from equations of vibration and heat conductivity balance, by introducing the vibrational temperature for each type of vibration. The inverse populations are determined as functions of the relative concentrations of CO_2, N_2, and He, their total pressure, the free electron density, and the discharge tube radius. The effect of these parameters on the laser output power is also estimated. The relations obtained show good qualitative agreement with the experimental curve; they also agree quantitatively within the accuracy of the assumed population model.

Keywords: CO_2 Vibrational Level Population, Parameter Study, Inverse Population

6. Silvus, Jr., H. S. and Bond, R. L.: Perforation of Plastic Films with Carbon Dioxide Laser Radiation. Final Report Contract No. DAAA21-68-C-0692, Southwest Research Institute, San Antonio, Texas, May 1968. Avail.: CFSTI CSCL 13/8.

Abstract: Perforation of the plastic film which forms the walls of a salt pellet sub-pack was accomplished using the focused beam from a carbon dioxide laser operating at 10.6 micrometers wavelength in the TEM_{00} mode. Typical hole sizes were 6 to 12 mils in diameter with two holes punched simultaneously, one in each of two layers of plastic film separated by approximately 0.2 inch. The holes thus obtained were clear of obstructions and had smooth, rounded edges. Polyethylene was found to yield the best results. A double exposure of the packet to the radiation produced the most reliable and consistent operation. Typical values of exposure were 100 milliseconds and 67 milliseconds respectively at a power level of 1.4 to 1.6 watts. A short production run was executed to provide a quantity of perforated salt pellet sub-packs for statistical evaluation. In addition, design details of a production line machine to perforate packets at a nominal rate of one packet per second was developed. A brief study to determine the feasibility of sealing and cutting polyethylene film using carbon dioxide laser radiation was accomplished. The results of this study indicate that sealing and cutting are feasible.

Keywords: Materials Cutting, Machining with CO_2 Laser

7. Collins, D. G. and Wells, M. B.: Scattering and Reflectance of Light from Airborne Laser System. Contract No. F19628-67-C-0298, Radiation Research Associates, Inc., Fort Worth, Texas, June 1968.
   Avail.: CFSTI CSCL 20/5.

   Abstract: The LITE-1 Monte Carlo program was used to predict the ground reflected and atmospheric scattered components of the scattered light from airborne laser systems received at collimated receivers located at the same altitude as the laser system and focused on the ground area illuminated by the direct radiation from the laser system. Lasers emitting light with wavelengths of 0.5145, 1.06, 3.507, and 10.6 micrometers were considered at different altitudes in two model atmospheres: The first atmosphere was a clear atmosphere having a ground level meteorological range of 25 km. The second atmosphere was identical to the first above 1.5 km, but below 1.5 km the aerosol content was increased to reduce the ground level meteorological range to 5 km. The ground reflected component of the scattered light entering the receiver for all four wavelengths was taken to be the sum of the direct radiation incident on the ground and reflected to the receiver plus the single scattered radiation incident upon the ground area illuminated by the direct radiation and then reflected to the receiver. For the 3.507 and 10.6 micrometer lasers, the atmospheric scattered component at the receiver in both atmospheres is composed almost entirely of single scattered light, but for the 0.5145 and 1.06 micrometer lasers, the single scattered irradiance seriously under-predicts the atmospheric scattered component for look-angles greater than just a few degrees.

   Keywords: Atmospheric Propagation, Ground Scattered Radiation

8. Kimmitt, M. F., Ludlow, J. H., and Putley, E. H.: The Use of a Pyroelectric Detector to Measure Q-Switched CO_2 Laser Pulses. Proceedings of the IEEE, Vol. 4, No. 7, July 1968, p. 1250.

   Abstract: A pyroelectric detector operating at room temperature and capable of resolving pulses of less than 1 microsecond duration is described.

   Keywords: Pyroelectric Detector, $Sr_{1-x}Ba_xNb_2O_6$ Detector

9. Hinkley, E. D., Harman, T. C., and Freed, C.: Optical Heterodyne Detection at 10.6 μm of the Beat Frequency Between a Tunable $Pb_{0.88}Sn_{0.12}$ Te Diode Laser and a CO_2 Gas Laser. Applied Physics Letters, Vol. 13, No. 2, July 15, 1968, pp. 49-51.

Abstract: Optical heterodyning between a CO_2 gas laser and a current-tunable $Pb_{0.88}Sn_{0.12}Te$ diode laser has been observed with both lasers in CW operation. The beat frequency was tunable from under 50 MHz to 1300 MHz and from 300 MHz to 3500 MHz for heterodyne experiments with the P(20) and P(18) CO_2 laser transitions, respectively.

Keywords: Heterodyne Detection, Beat Frequency, $Pb_{0.88}Sn_{0.12}Te$ Diode Laser

10. Yin, P. K. L. and Long, R. K.: Atmospheric Absorption at the Line Center of P(20) CO_2 Laser Radiation. *Applied Optics*, Vol. 7, No. 8, August 1968, pp. 1551-1553.

Abstract: Atmospheric absorption at the line center of P(20) CO_2 laser radiation has been calculated at different altitudes. In this calculation, the absorption caused by water vapor has not been included. The line strength and half-width at 295°K and 1 atm pressure used are $5.09 \times 10^{-4} \, cm^{-2} \, atm^{-1}$ and $0.07 \, cm^{-1} atm^{-1}$, respectively.

Keywords: Atmospheric Absorption, Line Strength, Atmospheric Propagation

11. Burak, I., Steinfeld, J. I., and Sutton, D. G.: CO_2 Laser Output Tuning by Selective Intracavity Absorption. *Journal of Applied Physics*, Vol. 39, No. 9, August 1968, pp. 4464-4465.

Abstract: Tuning has been accomplished by incorporating a prism or a grating in the laser cavity. From published operating parameters, both these schemes seem to degrade seriously the Q of the cavity. In their study of self-Q-switching, Wood and Schwarz noted that introduction of SF_6 into the cavity caused the output to switch from P branch to R branch. Hanst et al. also report that the output can be "pushed" by incorporating various gases in the cavity. This suggests that selectively absorbing gases might be used for sensitive fine-tuning of the laser output. The possible advantage of such a tuning scheme would lie in its ease of introduction into conventional laser systems, requiring no additional optical elements or cavity realignment. A similar technique has proven successful in tuning the output of dye solution lasers.

Keywords: Tunable Lasing, Selective Intracavity Absorption, SF_6 Absorption

12. Massachusetts Institute of Technology: Electrodynamics of Media. M.I.T. Electronics Laboratory Research Activities Report. Contract No. DA-28-043-AMC-D2536(E), July 15, 1968.

Abstract: If we apply the formula for the saturation power of a two-level system to the case of CO_2, using the relaxation time of the upper level as 10^{-3} sec., for the lower level 10^{-4} sec., and $t_{sp} = 5$ sec., we obtain a value that is too small compared with the experimentally observed value by a factor of 500 or 100, the value depending on the experiment that is used for comparison. In this report, we determine the cross relaxation of the rotational levels, by solving in closed form the rate equations in the limit when the vibrational relaxation times are long compared with the rotational relaxation times, a situation that holds in practice. It may be shown that the number of levels participating in CO_2 laser action is of the order of 15. Hence the discrepancy between the theoretically predicted value for the saturation power and the one observed experimentally cannot be explained solely by assuming cross relaxation of the rotational levels. We propose that the discrepancy can be explained by further assuming spatial diffusion of the unused populations into the laser beam, and we estimate the magnitude of this effect.

Keywords: Cross-Relaxation of Rotational Levels, Spatial Diffusion of Unused Levels, Saturation Power

13. Siekman, J. G. and Morijn, R. E.: The Mechanism of Welding with a Sealed-Off Continuous CO_2-Gas Laser. Philips Research Reports, Vol. 23, August 1968, pp. 367-374.

Abstract: A very simple high-power sealed-off CO_2-gas laser with an output of about 100 watts has been developed. Some experiments were performed on drilling and welding with the outcoming laser beam collimated by a Ge lens. The drilling rate and hole dimensions were measured as a function of the distance between work piece and the lens. From these results the optimum working distance was obtained. The welding phenomenon was investigated using a low-reflectivity material with poor heat conduction. The welding mechanism is described. On the basis of these results requirements can be drafted for the laser welding of solids of higher reflectivity and higher heat diffusivity.

Keywords: Welding with a CO_2 Laser, High Power Output, Sealed-Off System, Machining with a CO_2 Laser

14. Sobolev, N. N. and Sokovikov, V. V.: Oscillation Mechanism in CO_2. NASA TT-F-11884, August 1968.

Abstract: Processes producing population inversion of the vibration modes of a CO_2 molecule in CO_2 lasers are considered. It was

assumed that the main process causing upper laser level population is vibrational excitation of N_2 and CO molecules by electron impact and resonance transmission of oscillation energy to CO_2 molecules. There can be direct $00°1$ CO_2 level excitation by electrons as well, although the above-mentioned process alone can produce a pumping rate corresponding to observed values of specific oscillation power. The excitation rate of the lower laser level is described by the relaxation of the bending vibration mode. Hence, the introduction of foreign gases into the discharge tube, which increases the rate of the 01^10 CO_2 level destruction, is expected to produce an increase of the inversion laser level population. Addition of helium to CO_2 leads to a gas temperature drop resulting in reduced upper laser level destruction.

Keywords: Population Inversion Processes, Additive (He)

15. Mullaney, G. J., Christiansen, W. H., and Russell, D. A.: Fog Dissipation Using a CO_2 Laser. Applied Physics Letters, Vol. 13, No. 4, August 15, 1968, pp. 145-147.

Abstract: Laboratory measurements have been made of the evaporation rate of fog when subjected to an intensity of 5 to 50 W/cm^2 of 10.6-micrometer radiation. The measurements agree with calculations and show that most of the absorbed laser energy goes into heating the air by conduction from the droplet surface. This heated air induces a motion which prevents the laser from completely clearing the fog. A correlation is found which describes the visibility improvement as the fog and power density are varied.

Keywords: Fog Dissipation, Atmospheric Visibility Improvement using a CO_2 Laser

16. Glass, A. M.: Ferroelectric $Sr_{1-x}Ba_xNb_2O_6$ as a Fast and Sensitive Detector of Infrared Radiation. Applied Physics Letters, Vol. 13, No. 4, August 15, 1968, p. 147.

Abstract: It has been found that ferroelectric $Sr_{1-x}Ba_xNb_2O_6$ has a very large pyroelectric coefficient at room temperature for $0.25 <$ $x < 0.5$. This suggested that the material may be useful as a detector of infrared radiation. A detector, constructed with a value of $x = 0.33$, was successfully used at $300°K$ to detect single pulses of 10.6-micrometer radiation from a Q-switched CO_2 laser with a rise time of less than 30 nsec. Detectors with a low frequency responsivity of better than 10^4 V/W and a minimum detectable power of 4×10^{-9} W cm^{-1} $cps^{-1/2}$ are easily constructed. Methods of improving on these results are discussed.

Keywords: $Sr_{1-x}Ba_xNb_2O_6$ Detector, Pyroelectric Detector, Q-Switching

17. Smith, A. L. S.: The Effect of Gas Flow on the Composition and Power Output of a CO_2-He-N_2 Laser. Physics Letters, Vol. 27A, No. 7, August 26, 1968, pp. 432-433.

    Abstract: The molecular composition of a CO_2-He-N_2 flowing gas laser has been examined with a mass spectrometer. Carbon dioxide is converted to carbon monoxide and oxygen, the amount of conversion being related to variations in the laser power output.

    Keywords: Parameter Study, Dissociation of CO_2

18. Munnerlyn, C. R. and Latta, M.: Rough Surface Interferometry Using a CO_2 Laser Source. Applied Optics, Vol. 7, No. 9, September 1968, pp. 1858-1859.

    Abstract: The authors report the use of a CO_2 laser in making useful interferometric measurements on optically rough surfaces.

    Keywords: Interferometric Measurements, Rough Surface Interferometry, Liquid Crystal Detector

    Note: Text corrections appear in Applied Optics, Vol. 7, No. 12, December 1968, p. 2450.

19. Boyd, G. D., Bridges, T. J., and Burkhardt, E. G.: Up-Conversion of 10.6μ Radiation to the Visible and Second Harmonic Generation in HgS. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 9, Sept. 1968, pp. 515-519.

    Abstract: The frequency mixing of infrared signals with visible laser light in nonlinear crystals (here referred to as up-conversion) has been suggested as a possible means of detecting infrared signals by use of sensitive and fast visible wavelength detectors.

    Preliminary experiments are reported of the up-conversion of the CW 10.6μ CO_2 laser by phase-matched difference mixing in HgS with the CW 0.6328μ HeNe laser to produce 0.6729μ which is detected with an S-20 photomultiplier. Reasonable agreement with theory is obtained. No additional sources of noise due to up-conversion were observed, although the actual performance was limited by pump fluctuations.

    No attempt was made to produce a practical device competitive with existing photoconductive detectors. In principle this is possible but would require various improvements, which are outlined.

    As a preliminary to the above experiment we report the measurement of the nonlinear coefficient $d_{11} = (1.2 \pm 0.4) \times 10^{-7}$ ESU

in HgS for second harmonic generation (SHG) of the 10.6 micrometer laser to produce 5.3 micrometers.

Keywords: Second Harmonic Generation in HgS, Heterodyne Detection, Up-Conversion

20. Waksberg, A. L.: Stabilization of a CO_2 Laser Using a Three-Mirror Laser System. *IEEE Journal of Quantum Electronics*, Vol. QE-4, No. 9, Sept. 1968, pp. 532-533.

Abstract: This paper reports the stabilization of a CO_2 laser using (1) the laser line profile as the discriminating curve for moderate stability, and (2) a three-mirror system for higher stability.

Keywords: Stability Measurements, Three-Mirror Stabilization

21. Siddoway, J. C.: Calculated and Observed Laser Transitions using $C^{14} O_2^{16}$. *Journal of Applied Physics*, Vol. 39, No. 10, Sept. 1968, pp. 4854-4855.

Abstract: Laser transitions in two isotopes of CO_2 have been reported previously which, with ordinary $C^{12}O_2^{16}$, essentially covered the region from 9.2 to 11.4 micrometers. Wieder and McCurdy reported several P transitions of the $00°1 - 10°0$ band of $C^{12} O_2^{18}$. Jacobs and Bowers, using a mixture of $C^{13}O_2^{16}$, observed about 200 transitions in the regions corresponding to the calculated values of the P and R branches of both the $00°1 - 10°0$ and $00°1 - 02°0$ bands of the mixture. A line-by-line comparison of the observed and calculated values was not given due to limited calibration precision of their monochrometer. This note reports the extension of CO_2 laser wavelengths using $C^{14} O_2^{16}$ and compares the calculated and observed values for the P and R branches of the $00°1 - 10°0$ band for both the $C^{13}O_2^{16}$ and $C^{14}O_2^{16}$ isotopes.

Keywords: Wavelength Extension Using Isotopes, Isotope Laser, Calculated Laser Transitions

22. Gibson, A. F., Hughes, T. P., Kimmitt, M. F., and Hallin, R.: Plasmas Produced by Focused CO_2 Laser Radiation. *Physics Letters*, Vol. 27A, No. 8, Sept. 9, 1968, pp. 470-471.

Abstract: The spectra of multiply ionized atoms have been recorded from plasmas produced by focusing 0.35 MW Q-switched pulses from a CO_2 laser on to solid targets.

Keywords: Plasmas Produced by CO_2 Laser, Q-Switching (Rotating Mirror), Small Signal Gain, Stark Effect

23. Carroll, T. O. and Marcus, S.: A Direct Measurement of the Rotational Relaxation Time in CO_2. *Physics Letters*, Vol. 27A, No. 9, Sept. 23, 1968, pp. 590-591.

Abstract: The rotational relaxation time in CO_2 was measured by observing the gain of a single rotational-vibrational transition as a function of time following the onset of a Q-switched pulse on a neighboring transition. Evidence for rotational selection rules was found.
Keywords: CO_2 Rotational Relaxation Time, Rotational Selection Rules, Kinetic Temperature of Lasing Medium

24. Lawrence, T. R.: Survey of CO_2 Laser Development for Space Applications, NASA TN D-4794, Sept. 1968

Abstract: This report presents the status of CO_2 laser development. The first application of a CO_2 laser is expected to be in the development and testing of an optical communication link from a synchronous orbit to Earth using heterodyne detection. The transmitter for this link will be a small, low-powered, space-qualified CO_2 laser with stable, single frequency, single mode operation, and dependable, long operating life. In this report, the brief history of CO_2 laser development is surveyed and a simplified qualitative discussion of the CO_2 laser and the various additives is presented. Then the current level of development is compared to what is desired. It is found that the CO_2 laser is especially suited for single frequency operation; stable, single frequency CO_2 lasers have been built and tested in heterodyne communication systems in the laboratory. Many of the requirements for space qualification can be met by proper design.
Keywords: Heterodyne Detection, Communication with the CO_2 Laser, Satellite Communications Experiment

25. Cheo, P. K.: Relaxation of CO_2 Laser Levels by Collisions with Foreign Gases. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 10, Oct. 1968, pp. 587-593.

Abstract: Relaxation time of the $00°1$ upper and $10°0$ lower CO_2 laser levels as a function of H_2O, CO, and Xe gas pressure has been measured using the afterglow pulse-gain technique. Lifetime for these gas mixtures and also for mixtures of CO_2, CO_2-H_2, CO_2-He, and CO_2-N_2, obtained previously, are analyzed and compared with available ultrasonic and fluorescence data. Results indicate that the $10°0$ and 01^10 levels of CO_2 are strongly coupled and depletion of the lower laser level population is essentially limited by the relaxation rate of the 01^10 level. Other processes involving energy exchange between CO_2 and foreign gases are detailed.

Keywords: Additives (water vapor, CO, Xe), Laser Level Relaxation
Time, Parameter Study, Afterglow Pulse Gain Technique

26. Goodwin, F. E. and Nussmeier, T. A.: Optical Heterodyne Communications Experiments at 10.6μ. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 10, Oct. 1968, pp. 612-617.

Abstract: A 10.6-micrometer heterodyne communication system that is in operation over a 30-km (18-mile) path is described. Television signals have been transmitted over the beam by the use of optical FM achieved with internal electrooptic phase modulation of the transmitter oscillator. A frequency deviation of 3 MHz is thus obtained for a driving voltage of 1 kV compared with the fundamental frequency noise of the system of about 1 kHz. For clear-day operation, average carrier-to-noise ratios at the receiver approach 60 dB, and demodulated video signal-to-noise ratios average 50 dB. Optical propagation experiments reveal amplitude scintillation noise in excess of 20 dB, represented by fluctuations of ± 10 dB from the average carrier level. Other observations show that the 10.6-micrometer beam has a remarkable ability to penetrate fog. Data related to scintillation, visibility, temperature, humidity, and optical absorption are presented.

Keywords: Communication with CO_2 Laser, Atmospheric Propagation, Electro-optic Modulation, Television Signal Transmission, GaAs Modulator

27. Miyamoto, K., Kon, S., Morimoto, S., Yamamoto, J., and Yoshinaga, H.: Density Measurement of Plasma by CO_2 Laser Interferometer. Japanese Journal of Applied Physics, Vol. 7, No. 10, Oct. 1968, p. 1304.

Abstract: A method of using a CO_2 laser interferometer is described for the measurement of plasma densities in the intermediate range of 10^{14} to 10^{16} cm^{-3}.

Keywords: CO_2 Laser Interferometer, Plasma Density Measurements

28. Plotkin, H. H.: Laser Tracking and Communication with Satellites. NASA TM X-524-69-193, Goddard Space Flight Center, Greenbelt, Maryland, Oct. 1968.

Abstract: While the potential value of space communication using the optical spectrum is rapidly being developed, tracking of satellites with pulsed lasers has already been yielding valuable data for several years. Four U.S. satellites equipped with special passive retroreflectors are now being tracked, by ruby lasers, to a precision of about 1 meter. They are being used for evaluation of other tracking systems, improvement of

satellite orbits, and consequently improvement of our knowledge of station locations and the earth's gravity field. Further expected advance in precision, to study lunar motion, continental drift, earth wobble, etc., requires better lasers, detection systems, and telescopes. Satellite experiments with continuous lasers such as argon and carbon dioxide are also leading to new optical tracking and satellite navigation techniques. More important, they constitute the next logical steps in the development of optical space communication. Areas requiring immediate attention include study of atmospheric effects on the communication channel; improvement in the efficiency, stability, power, lifetime, and tunability of candidate lasers; development of wide-band radiation-cooled mixers at 10 microns; and development of techniques for acquiring and tracking satellite communication terminals, both from satellites and on the ground.

Keywords: Satellite Tracking, Spacecraft Communication, Range Errors, Detection, Communication with the CO_2 Laser

29. Novgorodov, M. Z., Sviridov, A. G., and Sobolev, N. N.: Electron Energy Distribution in Discharges Used for CO_2 Lasers. JETP Letters, Vol. 8, No. 7, Oct. 5, 1968, pp. 211-214.

Abstract: The pumping rate at the upper lasing level of a CO_2 laser depends not only on the electron concentration, but also on their energy distribution f(E). It is therefore possible to construct a theory of the operation of a laser of this type, and all the more to calculate the inverted population, only if the distribution function is known. There are practically no such data in the literature. The two- and single-probe methods with the usual procedure for processing the probe characteristics, used by Clark and by Smith, Bletzinger, and Garscadden to obtain the electron temperature, can hardly be applied to discharges in mixtures with CO_2. Their measurements have shown that in the absence of a Maxwellian energy distribution one cannot speak of an electron temperature in the usual sense.

Keywords: CO_2 Plasma, Electron Energy Distribution, Distribution Function

30. Andriakhin, V. M., Velikhov, E. P., Golubev, S. A., Krasil'nikov, S. S., Prokhorov, A. M., Pis'mennyi, V. D., and Rakhimov, A. T.: Increase of CO_2 Laser Power under the Influence of a Beam of Protons. JETP Letters, Vol. 8, No. 7, Oct. 5, 1968, pp. 214-216.

Abstract: The authors discuss the investigation of the production of electrons exciting the working levels of the molecules of a gas

laser discharge not in an electric discharge but by ionization
with fast charged particles. Such particles may be the products
of nuclear reactions, nuclear fission fragments, etc.

Keywords: Effect of Proton Beam on Power Output

31. Karlov, N. V., Petrov, Yu, N., and Stel'makh, O. M.: Control of the
Frequency of a CO_2 Laser by a Boron Trichloride Filter. JETP Letters,
Vol. 8, No. 7, Oct. 5, 1968, pp. 224-226.

Abstract: The authors present the results of experiments aimed at con-
trolling the frequency of a CO_2 laser by introducing into the
laser resonator a cell containing BCl_3 at pressures between
10^{-2} and 30 Torr.

Keywords: Frequency Control, BCl_3 Filter, Frequency Stability, Saturable
Filter

32. Boness, M. J. W. and Schulz, G. J.: Vibrational Excitation of CO_2 by
Electron Impact. Physical Review Letters, Vol. 21, No. 15, Oct 7, 1968,
pp. 1031-1034.

Abstract: Vibrational excitation of CO_2 is studied using a double electro-
static analyzer. The asymmetric stretch vibration (001) ex-
hibits a peak cross section about 3×10^{-16} cm^2 at 0.9 eV, and
the 002 mode excitation is an order of magnitude lower. Six
energy loss peaks associated with the symmetric stretch mode
(100,200, etc.) are observed in the energy range 3 - 4.5 eV,
with a peak at 3.8 eV. The data are consistent with the exist-
ence of two short-lived compound states. The first, around
0.9 eV, exhibits p-wave character, and the second, around
3.8 eV, exhibits s-wave behavior.

Keywords: Double Electrostatic Analyzer, Electron Impact Excitation,
Compound State Model

33. Duley, W. W.: CO_2 Laser-Induced Electron Emission from Metals.
Applied Physics Letters, Vol. 13, No. 8, Oct. 15, 1968, pp. 255-256.

Abstract: Thermionic emission from molybdenum and tungsten targets
irradiated with a cw CO_2 laser beam has been observed. The
incident energy is $\simeq 0.2 - 0.5$ J per pulse at a repetition rate
of 120 cps. Peak electron currents are 0.1 ma.

Keywords: Laser Induced Thermionic Emission

34. Brinkschulte, H. W.: Thermal Effects in Carbon Dioxide Lasers. ECOM-
3030, U.S. Army Electronics Command, Ft. Monmouth, N. J., Oct. 1968.

Abstract: Gas temperature and its distribution across the laser tube
were calculated from a simple energy equation. The calcula-
tions were carried out for CO_2 and CO_2-He discharges. The

necessary thermal conductivities for CO_2-CO- and CO_2-He-mixtures were determined for 300°K and 400°K. Good agreement has been found between the calculated temperatures and the spectroscopically determined values. Comparison of a CO_2 and CO_2-He discharge indicates that He does not lower the gas temperature significantly. However, the maximum of laser emission at the P(22) line in CO_2 is shifted to the P(20) line in CO_2-He mixtures.

Keywords: Thermal Effects, Additive (He), Gas Temperature Determination

35. Noon, J. H., Holt, E. H., Blaszuk, P. R., and Buser, R. G.: Electron Radiation Temperatures and Optical Gain Measurements in a CO_2 Laser Amplifier. Annual Report Rensselaer Polytechnic Institute. Contract No. DAAB07-0533, Oct. 1968.

Abstract: Combined optical gain at 10.6 micrometers and electron radiation temperature measurements at an X-band microwave frequency have been carried out on a small bore CO_2 laser amplifier. Measurements were made over an extended pressure range in a flowing gas system, studying the transition from gain to loss as well as conditions for maximum gain both for pure CO_2 and with N_2 and He as additives. No significant variation of the radiation temperature was observed, which shows that the addition of He does not cause a change in the average electron energy. Increased gain must therefore be attributed to the He directly affecting the excited CO_2 levels.

Keywords: Amplifier, Electron Radiation Temperatures, Gain

36. Patty, R. R., Manring, E. R., and Gardner, J. A.: Determination of Self-Broadening Coefficients of CO_2, Using CO_2 Laser Radiation at 10.6μ. Applied Optics, Vol. 7, No. 11, Nov. 1968, pp. 2241-2245.

Abstract: Essentially monochromatic radiation with a frequency corresponding to the frequency of the line center of the P(20) line of the 961-cm^{-1} CO_2 band was obtained from a CO_2 laser. Using this radiant energy, transmittances of CO_2 samples were measured as various broadening gases were added. Self-broadening coefficients of CO_2 relative to nitrogen, hydrogen, helium, and argon were determined from the measurements characterizing the transmittance only at the line center; from these measurements ratios of optical collision diameters are calculated.

Keywords: Self-Broadening Coefficients of CO_2, Line Broadening Gases, Additives (N_2, H_2, He, Ar)

37. Meyerhofer, D.: Q-Switching of the CO_2 Laser. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 762-769.

Abstract: ·The laser pulses obtainable from a Q-switched CO_2 laser are calculated and compared with the results of a number of different techniques of performing the Q-switching. The continuously operating laser is considered first. The transition rates between the molecular vibrational states and their occupations are derived from the measured CW power. The laser tube was 1.9 meters long, had a diameter of 2.4 cm, and used flowing CO_2-N_2-He gas. For rapid Q-switching, maximum pulses of 4.5 mJ energy and 85 ns half width are predicted. Such pulses were observed with a rotating mirror Q-switch. However, that technique has a limited pulse repetition rate and experiments on closely spaced pulses are difficult to interpret. A more flexible technique, which allows a much greater variation in the experimental parameters, is the use of a fast shutter to interrupt the laser beam in the cavity. While this switch is somewhat slower than the rotating mirror it does produce pulses of the same energy at repetition rates up to 5000 per second, and smaller pulses at any desired higher rate. From these measurements the upper and lower laser level lifetimes are deduced. They are found to agree well with the values obtained from the CW measurements.

Keywords: Q-Switching (Rotating Mirror), Pulse Rate, Q-Switching (Intra-Cavity Shutter), Laser Level Lifetimes, Reactive Q-Switching

38. Mocker, H. W.: Rotational Level Competition in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 769-776.

Abstract: Competition effects between rotational levels of the rotation-vibration band of CO_2 at 10.6 micrometers have been investigated in both traveling-wave and standing-wave CO_2 lasers operated in a single mode and single frequency. In a ring laser, Doppler shift and gain proportionality as a function of gas flow can be used to generate a gain anisotropy as a function of frequency so that the ring laser operates as a unidirectional oscillator. Over a narrow frequency interval, two rotational levels can be made to oscillate with oppositely directed traveling waves with an intensity crossover between the two Doppler centers. In this way, a discriminant can be derived that allows frequency stabilization to 5 parts in 10^{12} in frequency. In standing-wave lasers of high-frequency stability, the rotational level competition can be observed by synchronous detection of

a low-frequency variation of the heterodyne beat frequency
signal of two lasers. The competition effects are due to
intensity-dependent anomalous dispersion arising from
saturation.

Keywords: Line Competition, Frequency Stability, Index Saturation, Ring
Laser

39. Bridges, T. J., Haus, H. A., and Hoff, P. W.: Small-Signal Response
of Laser Amplifiers and Measurement of CO_2 Laser Linewidth. IEEE
Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968,
pp. 777-782.

Abstract: As part of a general program of research on time response of
a laser medium to optical transients, we have studied the linear
(small-signal) response to a rectangular pulse signal input,
both theoretically and experimentally.

The theory for the case of Lorentzian homogeneously and Gaus-
sian inhomogeneously broadened transitions has been developed
using a two-level density matrix formulation. The results are
negligibly different for the two broadening mechanisms for an
amplifying medium, where the line center contribution is most
important.

The step response of a laser is measured experimentally and
the bandwidth of the medium is deduced. Its pressure depend-
ence in a mixture of CO_2, N_2, He of 1:0.88:4.53 is determined.

Keywords: Amplifier, Small-Signal Response, Linewidth Measurements

40. Witteman, W. J.: High Power Single-Mode CO_2 Laser. IEEE Journal of
Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 786-788.

Abstract: The performance of a single-mode single-frequency CO_2 laser
operating on a single rotational-vibrational transition is de-
scribed. The laser is sealed off with a length of 152 cm, and
it has a continuous output power of 60 watts. Mode-competition
phenomena are of great importance in obtaining this high out-
put power of high spectral purity. In order to maintain the high
output power over a long period of time, we constructed our
laser with a water vapor replenisher and a bypass to reduce
gas segregation in the discharge. The use of a plane-parallel
germanium out-coupling window creates conditions for a single
rotational-vibrational transition. The experimental procedure
and results are discussed.

Keywords: High Power Output, Single-Mode Operation, Sealed System,
Additive (water vapor), Life Expectancy of Sealed System,
Zeolite, Mode Studies

41. Antropov, E. T., Silin-Bekchurin, I. A., Sobolev, N. N., and Sokovikov, V. V.: Gain Measurement in the CO_2 Laser Discharge. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 790-796.

Abstract: In order to examine the CO_2 laser oscillation mechanism, a measurement was made of the unsaturated gain of CO_2 laser radiation in an active medium of gas discharge containing CO_2, N_2, and He.

A two-beam optical balance method was used to measure the gain in an amplifier; the accuracy of the measurement was approximately 10 percent. The output of a CO_2-N_2-He laser was used as the radiation source. The absolute power of the probing beam, which has a diameter of approximately 5 mm, was maintained at approximately 15 mW. Saturation was not observed at probing signal levels up to 80 mW. Amplifier tubes with diameters of 55, 34, 12, and 5 mm were used. The dependence of the amplifier gain on the current density, pressure, composition of the gas mixture, and tube diameter was measured. Comparison was also made of the calculated and measured values of the laser population inversion.

Keywords: Unsaturated Gain Measurements, Amplifier Gain, Inverse Population

42. Gordiyets, B. F., Sobolev, N. N., Sokovikov, V. V., and Shelepin, L. A.: Population Inversion of the Vibrational Levels in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 796-802.

Abstract: The vibrational level populations in CO_2 lasers with mixtures of CO_2, N_2, CO, and He have been calculated using a method developed previously. A number of transition probabilities between the vibrational levels due to molecular collisions, the dependences of the population inversion upon various laser parameters (such as the total and partial pressures of the gases, electron density, and tube radius), and the radial profile of the laser gain are calculated in this paper. The calculations show that the CO molecules formed in the discharge play a significant role in the laser. The results given in this paper and others allow us to explain all the main characteristics of both the pumped and the sealed-off CO_2 lasers.

Keywords: Vibrational Levels in CO_2, Population Inversion, Radial Gain Profile, Effect of CO on Lasing

43. Miles, P. A. and Lotus, J. W.: A High-Power CO_2 Laser Radar Transmitter. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 811-819.

Abstract: Experiments on the amplification of CW and pulsed infrared signals at 10.6-micrometers wavelength have been carried out on CO_2 laser amplifiers excited by dc and pulsed electrical currents. Measurements of low signal gain, gain saturation, repetitive pulse amplification, and optical distortion have led to the design of a 1-kW average power transmitter with 10-microsecond infrared output pulses. The design, construction, and performance of this device are discussed. Measurements of pulse shaping, pulse-to-pulse stability, output beam divergence, and stability are outlined.

Keywords: High Power Output, Laser Radar, Amplifier Gain, Pulse-Excited Amplifier, Construction Details

44. Borde, C. and Henry, L.: Study of the Lamb Dip and of Rotational Competition in a Carbon Dioxide Laser. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 874-880.

Abstract: A monomode carbon dioxide laser, delivering a constant power on any rotational line of either the 10.6- or 9.4-micrometer band, has been achieved by control of the cavity frequency and of the gain. A piezoelectric ceramic has been used either for a frequency sweep of the cavity or for output stabilization at the bottom of the Lamb dip. This laser has been used for two studies.

1. Study of the Lamb dip in carbon dioxide. By applying a sawtooth voltage to the ceramic we have been able to record the profiles corresponding to the axial modes of the cavity. For low pressures of carbon dioxide and nitrogen, these profiles show a central tuning dip. The shape of the profile has been studied as a function of the pressure. If two lines are allowed to oscillate simultaneously, asymmetric profiles are obtained, since the gains are tightly coupled by rotational thermalization. This effect and its influence on the depth of the dip are analyzed.

2. Measurements of absorption coefficients of vibration-rotation lines of gases. Since the power output of our laser shows a relative stability of better than 10^3 for a few minutes and of about 5×10^2 for hours, we have performed measurements of absorption coefficients of gases absorbing the carbon dioxide laser radiation. As an example the absorption of P(20) by ammonia is given.

Keywords: Line Competition, Lamb Dip, Frequency Stability, Absorption Coefficient of Gases, Absorption Cell (Ammonia)

45. Brinkschulte, H. W.: The Influence of CO on CO_2 Laser Performance. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 948-953.

Abstract: Impurities are necessary to achieve considerable CW laser action in CO_2 since in pure CO_2 the disintegration of the lower laser level is too slow to maintain a substantial population inversion. The dissociation product CO, provided by the discharge itself if initially pure CO_2 is used in a sealed system, enhances the gain mainly because of its effectiveness in accelerating the relaxation of the first level of the bending mode to which the lower laser level relaxes. The characteristic time for energy exchange between these two levels is 20 ± 5 microseconds at 1 Torr, 400°K. Experiments in He-CO_2 mixtures support the assumption that the main influence of CO is to accelerate the decomposition of the lower laser level.

Keywords: Dissociation of CO_2, Additive (CO), Sealed System

46. Meyerhofer, D.: Measurement of the Beam Profile of a CO_2 Laser. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 969-970.

Abstract: Foamed polystyrene is used to form a permanent recording of infrared laser beams, from which the intensity distribution can be calculated quantitatively. Minimum-power densities of $450 \, mW/cm^2$ can be recorded. This technique is used to analyze the single-mode operation of a CO_2 laser.

Keywords: Beam Profile Measurement, Output Beam Pattern

47. Deutsch, T. F. and Horrigan, F. A.: Life and Parameter Studies on Sealed CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 11, November 1968, pp. 972-975.

Abstract: The life and power outputs of sealed CO_2 lasers with xenon and hydrogen additives have been investigated. The results confirm the usefulness of hydrogen for achieving long life, but suggests that the power increases previously observed with the addition of hydrogen may be due to changes in CO_2 concentration rather than to relaxation effects.

Keywords: Parameter Study, Life Expectancy of Sealed System, Additives (Xe, H_2)

48. Noon, J. H., Blaszuk, P. R., and Holt, E. H.: Electron Radiation Temperature Measurements in a CO_2 Laser Amplifier. Journal of Applied Physics, Vol. 39, No. 12, November 1968, pp. 5518-5520.

Abstract: An experiment is described which shows that no significant variation in average electron energy is associated with changes

in optical gain in a 10.6 micrometer laser amplifier containing CO_2 mixed with N_2 and He. A microwave technique for measuring the average electron energy has been developed, using a 4-mm-bore discharge tube sealed by NaCl windows and enclosed in an X-band waveguide section.

Keywords: Electron Density Measurements, Amplifier, Electron Radiation Temperature, Amplifier Gain

49. Groh, G.: Vacuum Deposition of Thin Flims by Means of a CO_2 Laser. Journal of Applied Physics, Vol. 39, No. 12, November 1968, pp. 5804–5805.

Abstract: In this communication the authors propose the use of a high-power continuous-wave CO_2 laser for vacuum deposition of thin films and report the results of some preliminary measurements.

Keywords: Vacuum Deposition of Thin Films

50. Treacy, E. B.: Generation of Chirped Pulses at 10.6 Microns Wavelength. Proceedings of the IEEE, Vol. 56, No. 11, November 1968, pp. 2053–2054.

Abstract: Pulses in which the carrier frequency is swept through about 60 MHz have been generated with a CO_2 laser. The technique uses an offset rotating mirror. The pulse energy is about 2×10^{-4} joule.

Keywords: Chirped Pulse Generation, Pulse Compression

51. Almer, F. H. R., Koedam, M., and Ter Kuile, W. M.: Influence of Hydrogen and Oxygen on the Gas Composition of a Sealed-Off CO_2 Laser-Systems. Zeitschrift für angewandte Physik, Vol. 25, No. 3, November 3, 1968, pp. 166–167.

Abstract: In this paper an experimental set-up is described which permits a quantitative analysis of the gas components in the laser during operation. For this purpose the sealed-off system is replaced by a system with slowly flowing gas. Detection of H_2O is done with an electrolytic cell; a mass spectrometer is used for the analysis of the other gas components. If no H_2 is added to the gas mixture, the measurements show a dissociation up to 50% of the CO_2 into CO and O_2. If, however, 1% H_2 and 0.5% O_2 are added only a small degree of dissociation of the CO_2 is found. In the gas discharge 10-20% of the H_2 reacts with O_2, forming H_2O.

Keywords: Sealed System, Additives (H_2, O_2, water vapor), CO_2 Dissociation, Gas Composition Determination

52. Sugiyama, A. and Inaba, H.: Simultaneous Laser Action of CO_2 and N_2O Molecules in a Gas Laser System of CO_2-N_2 Mixture. Physics Letters, Vol. 28A, No. 2, November 4, 1968, pp. 120-121.

Abstract: The simultaneous laser emission in both P branches of the CO_2 and N_2O molecules in the 10 micrometer band was observed during the discharge of CO_2-N_2 mixture in a gas laser system.

Keywords: N_2O Lasing, Dissociation Energy of CO_2, Additive (N_2O)

53. Warner, J.: Spatial Resolution Measurements in Up-Conversion from 10.6 Micrometers to the Visible. Applied Physics Letters, Vol. 13, No. 10, November 15, 1968, pp. 360-362.

Abstract: 10.6-micrometer radiation from a pair of point sources at optical infinity has been mixed with collimated ruby-laser radiation in Proustite. The sum-frequency radiation at 6516 Å so produced was then focused with a camera lens to form a visible image of the infrared sources. With a pump-laser beam divergence of 1.2 mrad the minimum resolvable angular separation of the infrared sources was 15 mrad according to the Rayleigh criterion.

Keywords: Spatial Resolution Measurements, Proustite, Up-Conversion

54. Lipa, M.: A Carbon Dioxide Gas Laser for Continuous Heating of the Plasma Source in the 'Wendelstein' Stellarators. Institut für Plasmaphysik G.m.b.H., Garching (West Germany). IPP-2/73, Avail: CFSTI (IPP-2/73), November 1968.

Abstract: A CO_2-gas laser which radiates about 150 watts in the wavelength region around 10.6 micrometers has been built. This light power is high enough to heat the plasma source, a tantalum sphere of 3 mm diameter, up to an equilibrium temperature of 2600°K.

Keywords: Plasma Source (Tantalum Sphere), High Power Output

55. McElroy, J. H., Flagiello, S. C., McDay, J. B., and Walker, H. E.: A Guide to the Literature on Carbon Dioxide Lasers (1 January 1964 - 30 June 1968). NASA TM X-524-68-435, Goddard Space Flight Center, Greenbelt, Md., November 1968.

Abstract: The results are presented of a literature search on carbon dioxide lasers. The results are presented in a chronological listing in which each item contains three sections: (1) a standard bibliographical listing, (2) an abstract of the paper or article, and (3) a comprehensive listing of keywords or phrases extracted from the publication.

Keywords: Bibliography

56. McElroy, J. H., McAvoy, N., Richard, H. L., Richards, W. E., and Flagiello, S. C.: An Advanced 10.6-Micron Laser Communication Experiment. NASA TM X-524-68-478, Goddard Space Flight Center, Greenbelt, Md., November 1968.

Abstract: The purpose of the proposed laser intersatellite communication experiment is to determine the capability of the carbon dioxide laser to meet the high data rate, intersatellite communication requirements envisioned for the late 1970's and 1980's. The experimental package to be developed consists of a 100 MHz bandwidth communication unit for synchronous satellite to synchronous satellite applications and a 5 MHz bandwidth communication unit for low-altitude satellite to synchronous-satellite applications. The proposed development will result in the production of a complete breadboard communication system, in near space-qualified form, that will be available in 1972 for use in appropriate spacecraft during the 1970's. The system will be developed to the point that placing the experimental package on a given satellite will consist primarily of space-qualification, packaging, interfacing the system to the spacecraft, and test and evaluation.

Keywords: Communication with the CO_2 Laser, Satellite Communications Experiment, ATS Satellite, Intersatellite Communications

57. Demma, F. J.: A Large Volume TEM_{00} Mode Technique for 10.6μ Lasers Applied Optics, Vol. 7, No. 12, December 1968, pp. 2420-2421.

Abstract: The author discusses several techniques designed to provide a large amount of power in a single transverse mode for use in a 10.6 micrometer laser radar transmitter.

Keywords: Laser Radar, TEM_{00} Mode, Cavity Configuration, Mode Control

58. Ohtsuka, Y., Tsukamoto, M., Masutani, K., and Yoshinaga, H.: A CO_2 Q-Switched Laser and its Nonlinear Amplification Characteristics. Japanese Journal of Applied Physics, Vol. 7, No. 12, December 1968, pp. 1510-1517.

Abstract: There have been observed 95 lines oscillating simultaneously in the $00°1-10°0$ and $00°1-02°0$ vibrational-rotational bands. The thermalization time among the rotational levels is deduced to be about 10^{-7} sec from the Q-switching time at which the competition among the laser oscillation lines disappears. The peak output power in the pulsed discharge was five times as large as that in the d.c. discharge. The giant pulse became markedly narrow when an aperture was introduced into the

resonator. Peak amplification by a factor of 10 was accompanied with pulse sharpening by using a multiple reflection amplifier tube. Normal laser oscillation was completely quenched by irradiation of a giant pulse. Two giant pulses closely spaced by 10 to 40 microseconds were generated using a pair of fixed reflectors at the rear end of the resonator. The lifetime of the lower laser level is estimated from the competitive interaction between the two pulses.

Keywords: Rotational Level Thermalization Time, Q-Switching (Rotating Mirror), Lower Laser Level Lifetime, Amplifier Gain, Nonlinear Amplification, Optimum Coupling (Aperture) Size

59. Konjevic, N. and Hearne, K. R.: Measurement of Arc Electron Densities Using a CO_2 Laser. Physics Letters, Vol. 28A, No. 5, December 16, 1968, pp. 309-310.

Abstract: This letter describes the application of a carbon dioxide laser interferometer to the measurement of electron density in an arc plasma. Results are given for the axial electron density in argon with a current range of 30 to 90 amperes.

Keywords: Arc Electron Density Measurements, Plasma Electron Density

60. Hanst, P. L. and Morreal, J. A.: A Wavelength-Selective Repetitively Pulsed CO_2 Laser. Applied Optics, Vol. 8, No. 1, January 1969, pp. 109-115.

Abstract: A CO_2 laser has been constructed and operated with two gas absorption cells built into the cavity. The first of the cells contains a gas that controls the wavelength of emission. The second contains a gas that forces the laser into a high frequency pulsed mode of operation. Details of the laser construction are given. The pulsing and wavelength shifting are accounted for by the spectroscopic and kinetics properties of the gases. The proper choice of absorbing gases has produced high powered pulsed operation at various wavelengths between 9.08 and 10.6 micrometers at repetition rates up to 100 kHz. Applications and advantages of the wavelength-selective, repetitively pulsed laser are discussed.

Keywords: Intracavity Gas Absorption Cell (propane, propylene), Sealed-Off System, Additives ($C^{12}O_2^{18}$), Pulsed CO_2 Laser (formic acid vapor, propylene gas, CO_2)

61. Carbone, R. J.: Characteristics of a Single-Frequency Sealed-Off CO_2 Amplifier. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 1, January 1969, pp. 48-49.

Abstract: The measured small-signal gain of 4.8 dB/m for a sealed-off CO_2 amplifier with average bore of 25 mm compares favorably with the highest gain published for a flowing-gas type. The saturated gain for this 9-meter amplifier was 1.2 dB/m with 95-watts output when sealed off and 1.3 dB/m with 110 watts output for a flowing-gas system.
Keywords: Amplifier (Sealed-Off), Gain Saturation, Gain, Small-Signal Gain, Single Frequency Operation

62. Inaba, H. and Ito, H.: Self-Locking Operation of a CO_2 Laser. _Laser Focus_, Vol. 5, No. 1, January 1969, p. 25.

Abstract: This paper reports the first observation of self-mode locking of a carbon-dioxide laser in which higher-order transverse modes are allowed to oscillate.
Keywords: Self-Mode Locking, Mode Beats (Frequencies)

63. Mikaelyan, A. L., Korovitsyn, A. V., Naumova, L. B., and Arsenyeva, S. M.: The Realization of Single-Mode Operation in a CO_2 Laser. _Radio Engineering and Electronic Physics_, Vol. 14, No. 1, January 1969, pp. 93-95.

Abstract: Results are presented of a study of the output power and spectrum of a CO_2 beat oscillator as a function of the length of the plano-spherical resonator. The possibility of achieving single-mode operation in such a system is shown.
Keywords: Luminescence Spectrum, Single Frequency Operation, Output Power Dependence upon Cavity Resonance Length

64. Sharma, R. D.: Near-Resonant Vibrational Energy Transfer Among Isotopes of CO_2. _Physical Review_, Vol. 177, No. 1, January 5, 1969, pp. 102-107.

Abstract: Quantitative calculations are presented which show that large (approximately gas kinetic) cross sections observed for vibrational-vibrational energy transfer between isotopes of CO_2 are due to long-range forces. The mechanism involved in the transfer of a quantum of asymmetric stretch vibration from $C^{12}O_2^{16}$ to $C^{12}O_2^{16}$ and $O^{16}C^{12}O^{18}$ can be described in terms of dipole-dipole coupling. However, dipole-dipole coupling is too weak to describe the energy transfer to $C^{13}O_2^{16}$. It is shown that in this case dipole-octupole coupling is expected to be stronger than dipole-dipole coupling. The room-temperature results are reproduced by assuming a value of 1×10^{-67} stat C^2 cm^6 for the square of the matrix element for the vibrational transition. Temperature dependence of the rate constant is calculated to put this hypothesis to test.

65. Cheo, P. K. and Abrams, R. L.: Rotational Relaxation Rate of CO_2 Laser Levels. Applied Physics Letters, Vol. 14, No. 2, January 15, 1969, pp. 47-49.

Abstract: The rotational relaxation rate constant k_{rot} of the CO_2 upper laser level has been determined by observation of the transient change in the CW gain of a 9.6-micrometer P(20) laser ampli- fier induced by passage of a 20-nsec 10.6-micrometer P(20) laser pulse through the amplifier.

66. Cool, T. A. and Shirley, J. A.: Gain Measurements in a Fluid Mixing CO_2 Laser System. Applied Physics Letters, Vol. 14, No. 2, January 15, 1969, pp. 70-72.

Abstract: Small-signal gain coefficients for the P(18) vibration-rotation transition of CO_2 at 10.57 micrometers have been measured in a high-velocity gas flow system utilizing the rapid mixing of vibrationally excited N_2 with initially unexcited CO_2. These measurements demonstrate that very high gain coefficients which are approximately independent of dimensions transverse to the flow can be realized in high-speed flow systems.

67. Bleekrode, R.: A Study of the Spontaneous Emission from CO_2-N_2-He-H_2 Laser Discharges $C^3\pi_u$ - $B^3\pi_g$ Emission Bands of N_2. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 2, February 1969, pp. 57-60.

Abstract: Results of spectroscopic investigations of the spontaneous emission of CO_2 lasers are presented. The band head emis- sion in the Second Positive System of N_2 is studied as a func- tion of discharge current and laser output power. The observed changes of the band head intensities are described in terms of the vibrational energy distribution in the $C^3\pi_u$ electronic state of N_2. A simple model is developed by which the influence of the laser process can be understood. The excitation proper- ties of the $C^3\pi_u$ state are in reasonable agreement with the predictions of this model.

68. Karlov, N. V., Konev, Yu. B., Kuz'min, G. P., and Prokhorov, A. M.: A Study of Inversion in a CO_2 Laser with Pulsed Pumping. Radio Engineering and Electronic Physics, Vol. 14, No. 2, February 1969, pp. 273-277.

Abstract: The variation with time of inversion for pulsed pumping of a CO_2 laser as a function of the amount of helium in the gas discharge mixture has been studied experimentally and theoretically. The theoretical and experimental results agree qualitatively.

Keywords: Q-Switching (Modulated), Plasma Thermal Conductivity, Inversion Mechanism

69. Mocker, H. W.: A 10.6μm Optical Heterodyne Communication System. Applied Optics, Vol. 8, No. 3, March 1969, pp. 677-684.

Abstract: A 10.6-micrometer optical heterodyne communication system is described that uses two stable single mode and single frequency CO_2 lasers of high frequency stability. Wavelength control on both lasers allows the use of one and the same transition of the rotation-vibration band of CO_2 around 10.6 micrometers. The system has a bandwidth of 1 MHz and simultaneous operation in baseband and on a 50 kHz carrier has been achieved. Heterodyne detection with mercury cadmium telluride detectors yielded signal-to-noise ratios within 3 dB of the coherent photon noise limit.

Keywords: Communication with CO_2 Laser, Heterodyne Detection, Single-Frequency Operation, Stability Measurements and Stabilization, Frequency Instability

70. Davis, W. C. and Cathey, Jr., W. T.: Beam Splitters for CO_2 Lasers. Applied Optics, Vol. 8, No. 3, March 1969, pp. 715-716.

Abstract: The construction of thin film-coated salt beam splitters for use in the 9-10 micrometer region is described. The design of the beam splitter for varying splitting ratios is discussed, and curves are presented which show the reflectivity of zinc selenide on sodium chloride as a function of film thickness in wavelengths and incident angle. The purpose of this work was to obtain beam splitters with low loss due to absorption or scattering. Expressions governing reflection and transmission for a three-layer dielectric medium are obtained and design parameters are given for the beam splitters. Experimental verification of the values was obtained.

Keywords: Beam Splitter (Salt)

71. Karlov, N. V., Konev, Yu. B., Koozmin, G. P., and Prokhorov, A. M.:
Pulsed CO_2 Laser with Double Modulation. IEEE Journal of Quantum
Electronics, Vol. QE-5, No. 3, March 1969, pp. 137-139.

Abstract: For the pulse pumped CO_2 laser we used Q-switching to in-
vestigate inversion kinetics. The pump was synchronized
with the Q-switching mirror. It was possible to obtain the
Q-switch pulses at any phase of the pump pulse. The re-
petition rate was 50 Hz and the pump pulse duration was 4
or 10 ms. It was found that there is an optimum delay in
switching the cavity Q-factor after the discharge started.
The giant pulse intensity increased several times after the
discharge was switched from CW to pulses. The inversion
rise time was 1-2 ms and its lifetime was strongly depen-
dent on the discharge current, due to plasma heating during
the current pulse. Increasing the helium percentage in the
discharge prolonged the inversion lifetime because of high
thermal conductivity of helium gas.

Gaseous BCl_3 was chosen to obtain the CO_2 laser giant pul-
ses with bleachable filter. The vibronic frequency V_3 of the
$B^{11}Cl_3$ molecules coincides with the P lines of the CO_2
laser. Rarer $B^{10}Cl_3$ corresponds to less active R lines.
Pure BCl_3 did not give the giant pulses. Adding helium to
the BCl_3 cell gave the pulses. The best results came from
adding very small amounts of ammonia NH_3 because of the
effective vibrational energy transfer between colliding BCl_3
and NH_3 molecules.

Keywords: Bleachable Cell Q-Switching, BCl_3 Cell, Q-Switching (Ro-
tating Mirror), Pulsed Pumping, Inversion Lifetime, Mod-
ulated Q-Switching

72. Brzbazovsky, Yu. V., Chebotayev, V. P., and Vasilenko, L. S.: Col-
lision Effect on the Saturation Character of Vibration-Rotation Transitions
for 00° 1-10°0 Band of CO_2. IEEE Journal of Quantum Electronics, Vol.
QE-5, No. 3, March 1969, pp. 146-151.

Abstract: Experimental studies of collision effects on the saturation
characteristics of vibration-rotation transitions for 00°1 -
10°0 band of CO_2 is described. Saturation was studied in
a passive absorption cell inside the laser resonator. The
saturation value could be varied by varying the cell tem-
perature and the pressure of CO_2. Vibration-rotation trans-
itions, at pressures greater than or equal to 1 mmHg, were
found to be saturated homogeneously, in spite of the fact that

the Lorenz width was much less than the Doppler width. This is explained by the high number of collisions during the life-time in a vibrational state. In this case the spectrum of a single molecule corresponds to that of a Doppler profile.

Cross sections for the destruction of levels of $00°1$-$10°0$ by added gases have been obtained, which at $t = 800°K$ appeared to be $\sigma_{CO_2\text{-}He} = 6 \times 10^{-19}$; $\sigma_{CO_2\text{-}Ne} = 2.8 \times 10^{-18}$; $\sigma_{CO_2\text{-}CO_2} = 6.6 \times 10^{-18}$; $\sigma_{CO_2\text{-}N_2} = 1.2 \times 10^{-17}$ cm^2. The introduction of sufficiently large absorption caused self-sustained radiation pulsation.

When the field influenced the saturating system for only a short period of time, with the interaction time being commensurate with the period of time between collisions, the line was saturated nonhomogeneously. This was expressed by the fact that with the scanning of the laser frequency, a peak power output was observed, corresponding to Lamb's hole, in the center of a saturation line.

Keywords: Collision Effects, Additives (Ne, He, N_2), Saturation Mechanisms, Linewidth, Hole Burning

73. Arakeyan, V. S. and Karlov, N. V.: Translucent Filter in a CO_2 Laser with Active Q-Modulation. Radio Engineering and Electronic Physics, Vol. 14, No. 3, March 1969, pp. 488-489.

Abstract: In this communication the authors report some experimental results dealing with the attempt to increase the pulse power output of the CO_2 laser with active Q-modulation by introducing a container with BCl_3 gas into the resonator.

Keywords: BCl_3 Cell, Q-Switching (Absorption Cell), Q-Switching (Beam Interrupting)

74. Danishevskii, A. M., Fishman, I. M., and Yaroshetskii, I. D.: Investigation of the Laser Effect in CO_2 During Pulsed Excitation. Soviet Physics - JETP, Vol. 28, No. 3, March 1969, pp. 421-424.

Abstract: Processes occurring in a pure CO_2 laser during pulsed excitation were investigated. A complex spectral and time dependence of the generation of two lines at 9.5 and 10.6 micrometers was observed. A study of the dependences of the pulse amplitude and emission lag on the electron energy showed that electron impact was the decisive mechanism. Maximum power was obtained for the 9.5 micrometer line; it was 5 kw for a pulse of 1 to 2 microseconds duration.

Keywords: Pulsed Operation, Additive (CO, N_2), Excitation Mechanisms, Emission Lag, Electron Impact Excitation

75. Vasil'yev, V. and Yevgen'yev, V.: Carbon Dioxide Laser in Space Communications. Joint Publications Research Service, Washington, D. C., March 3, 1969. JPRS-47557.
   Abstract: A nontechnical account of the discoveries of the ruby laser and the carbon dioxide laser is given. Properties of two lasers used as space communicators are discussed.
   Keywords: Communication with the CO_2 Laser, Space Communication with the CO_2 Laser

76. McCoy, J. H. and Long, R. K.: P(20) and P(16) Carbon Dioxide Line Strengths Determined from Transmittance Measurements in the Doppler Region. Applied Optics, Vol. 8, No. 4, April 1969, pp. 834-835.
   Abstract: The strengths of the carbon dioxide lines in the 10.4-μm band can be determined directly from the line center transmittance of carbon dioxide at pressures sufficiently low so that the lines have a pure doppler profile. We have determined the line strengths of the P(20) and P(16) lines from the line center transmittance of carbon dioxide at pressures below 45 mTorr. The transmittance was measured over a 1040-m path in a multipass absorption cell using a carbon dioxide laser source.
   Keywords: Line Strength, Transmittance of CO_2, Doppler-Lorentz Absorption Coefficient

77. Abrams, R. L. and Gandrud, W. B.: A Variable 10.6-μ Attenuator. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 4, April 1969, pp. 212-213.
   Abstract: A variable CO_2 laser attenuator with a dynamic range of 33dB, large power handling capability, and reproducible attenuation has been constructed.
   Keywords: Variable Attenuator for 10.6 Micrometers

78. Levinson, G. R., Sviridov, A. N., Tychinskiy, V. P., and Frolova, V. G.: Measurement of the Lifetimes of the 00°v System of Vibrational Levels of CO_2 Molecules. Radio Engineering and Electronic Physics, Vol. 14, No. 4, April 1969, pp. 580-585.
   Abstract: The lifetimes of the 00°v system of vibrational levels of CO_2 molecules have been investigated in pure CO_2 and in mixtures of CO_2 with He and air both when a current is flowing in the mixture and also in the absence of a discharge current.

A nomogram is presented, permitting one to determine the lifetime of the $00°v$ levels of CO_2 (for any mixtures of CO_2, He and air usable in CO_2 lasers) for a gas temperature of $300°K$ and no discharge current. The dependence of the lifetimes of the $00°v$ levels of CO_2 on the discharge current and on the power, dissipated in the discharge, was investigated.

It is known that the decrease in lifetime when pumping is present is caused by a heating of the gas. A method is proposed for estimating the lifetime in the presence of pumping.

Keywords: Additive (He, Air), Laser Level Lifetimes, Relaxation Processes

79. Levinson, G. R., Sviridov, A. N., Tychinskiy, V. P., and Frolova, V. G.: The Variation of the Population of the $00°1$ Level of CO_2 Molecules. Radio Engineering and Electronic Physics, Vol. 14, No. 4, April 1969, pp. 586-588.

Abstract: A method is described for measuring the population of the $00°1$ level of CO_2 molecules. Results of the measurements of the population of the CO_2 $00°1$ level under conditions corresponding to a CO_2 pulsed laser mode of operation are presented.

Keywords: Population of $00°1$ Level, Pulsed Mode Excitation

80. Biryukov, A. S., Gordiets, B. F., and Shelepin, L. A.: Obtaining Inverted Population on Vibrational Levels of Polyatomic Molecules. Soviet Physics – JETP, Vol. 28, No. 4, April 1969, pp. 762-768.

Abstract: A number of typical polyatomic molecules (N_2O, SO_2, CS_2, C_2N_2, HCN, H_2O) are investigated on the basis of the relaxation model proposed for the analysis of the operation of a CO_2 laser. The probabilities of the collision transitions that determine the relaxation of the vibrational energy and its pumping from the N_2 (or CO) molecule are calculated. The relaxation in electric discharges in various molecular gases are calculated. The possibilities of producing population inversion of the vibrational levels are investigated. Lasing in a large number of molecules is explained on the basis of the proposed approach. The estimates confirm the mechanism of generation on the $11^1 0 - 04^0 0$ transition of HCN. An explanation is proposed for the generation mechanism on several transitions in H_2O. The results make it possible to carry out a qualitative analysis and a fruitful search for other polyatomic gases suitable for lasing.

Keywords: Population Inversion Mechanism, Relaxation Processes

81. Krupke, W. F.: Passive Q-Switching of a CO_2 Laser Using a Mixture of SF_6 and C_2F_3Cl Gases. Applied Physics Letters, Vol. 14, No. 7, April 1, 1969, pp.221-222.

Abstract: Passive Q-switching of a CO_2 laser operating at 10.6 micrometers has been achieved with a mixture of sulfur hexafluoride and chlorotrifluoroethylene gases contained in a gas cell placed within the resonator. Use of chlorotrifluoroethylene gas to suppress spurious oscillations eliminates the need to use dispersive optical elements in the resonator.

Keywords: Passive Q-switching, SF_6 Absorption Cell, C_2F_3Cl Absorption Cell

82. Alimpiev, S. S., Karlov, N. V., Konev, Yu. B., Koozmin, G. P., and Petrov, R. P.: Influence of Dissociation on the Inversion of a CO_2 Laser with Pulsed Pumping. JETP Letters, Vol. 9, No. 7, April 5, 1969, pp. 223-225.

Abstract: In this paper the authors report the results of experiments aimed at determining the dependence of the inversion in a CO_2 laser on the pump pulse repetition frequency. They have found that the dissociation of the CO_2 molecules greatly decreases the inversion with increasing repetition frequency, and that an increase of the amount of helium in the gas-discharge mixture greatly weakens this decrease.

Keywords: Pump Pulse Repetition Frequency, Population Inversion, Additive (He), Relaxation Rate, CO_2 Dissociation, Amplifier

83. Gordon, P. L., Schwarz, S. E., Shank, C. V., and Wood, O. R.: Continuous Infrared Parametric Amplification in a Saturable Absorber. Applied Physics Letters, Vol. 14, No. 8, April 15, 1969, pp. 235-237.

Abstract: Continuous parametric amplification of signals near 10.6 micrometers has been obtained. Amplification is caused by interaction with a strong pumping beam in sulfur hexafluoride gas, a saturable absorber. Nonlinear polarization of individual SF_6 molecules is considered to be responsible.

Keywords: SF_6 Absorber, Parametric Amplification, Saturation Parameter, SF_6 Fluorescence Decay Time, SF_6 Cell Amplifier

84. Abrams, R. L. and Dienes, A.: Cross Saturation of 10.6μ Signals in SF_6. Applied Physics Letters, Vol. 14, No. 8, April 15, 1968, pp. 237-240.

Abstract: Measurements of the nonlinear interaction in SF_6 of two linearly polarized CO_2 laser signals as a function of the

angle between the two planes of polarization have been made. The angular dependence of the interaction suggests that several SF_6 vibrational-rotational transitions are responsible for 10.6 micrometer absorption.

Keywords: SF_6 Absorption Cell, SF_6 Unsaturated Absorption Coefficient, Photon Echo in SF_6

85. Nighan, W. L. and Bennett, J. H.: Electron Energy Distribution Functions and Vibrational Excitation Rates in CO_2 Laser Mixtures. Applied Physics Letters, Vol. 14, No. 8, April 15, 1969, pp. 240-243.

Abstract: The electron energy distribution function has been calculated for the plasma of a CO_2-N_2-He mixture using available electron-molecule cross-section data. Rates at which electrons transfer energy to the inelastic levels of CO_2 and N_2 were then determined. With this information, the relationship of the various electron-molecule energy exchange processes to laser performance was studied. For conditions typical of CO_2 lasers, approximately 17% of the power transferred to the CO_2 and N_2 was found to be available for conversion to optical power. Estimates of maximum available optical power were made and found to be consistent with experimental values.

Keywords: Electron Energy Distribution Functions, Electron Energy Transfer Rates, Additive (CO), Electron Temperature, Power Transfer within Plasma

86. Bridges, T. J. and Chang, T. Y.: Accurate Rotational Constants of $C^{12}O_2^{16}$ from Measurement of CW Beats in Bulk GaAs between CO_2 Vibrational-Rotational Laser Lines. Physical Review Letters, Vol. 22, No. 16, April 21, 1969, pp. 811-814.

Abstract: A room-temperature bulk GaAs mixer is used to mix frequencies of pairs of CW vibrational-rotational CO_2 laser lines, each stabilized to line center. The beat frequencies, in the millimeter-wave region of 50-80 GHz, are measured for 37 pairs of transitions to better than 1 MHz. The deduced rotational constants for the relevant vibrational levels ($00°1$, $10°0$, $02°0$) are 25 to 200 times more accurate than the best previous results (from conventional spectroscopy).

Keywords: Beat Frequency, Rotational Constants, GaAs (bulk) Mixer, PZT Frequency Stabilization

87. McElroy, J. H., Cohen, S. C., and Walker, H. E.: First Summary Design Report, ATS-F Laser Communication Experiment, Infrared Mixer

and Radiation Cooler Subsystem. NASA TM X-524-69-227, Goddard Space Flight Center, Greenbelt, Md., April 1969.

Abstract: This report reviews the required subsystem performance for the ATS-F Laser Communication Experiment, Infrared Mixer and Radiation Cooler Subsystem. A laser heterodyne test set-up for determining infrared mixer parameters is described. The properties of mercury cadmium telluride infrared mixers are reviewed.

Keywords: Satellite Communication Experiment, ATS Satellite, Infrared Mixer, Radiation Cooler, HgCdTe Mixer

88. Yin, P. K. L.: Studies on CO_2 Isotope Molecules and Atmospheric transmission of $^{12}C^{18}O_2$ Laser Radiation. Applied Optics, Vol. 8, No. 5, May 1969, pp. 997-1006.

Abstract: Three normal frequencies, nine anharmonic force constants, and the moment of inertia of isotope CO_2 molecules are determined from spectroscopic data on $^{12}C^{16}O_2$. These constants are used in predicting the wavelengths of various transitions for different isotopic substituted carbon dioxide. Comparisons are with those observed experimentally. Using the predicted wavelength of P(20) absorption coefficient, the atmospheric transmission of $^{12}C^{18}O_2$ is also calculated.

Keywords: Spectroscopy, Atmospheric Transmission, Isotope Laser, CO_2 Anharmonic Force Constant, CO_2 Moment of Inertia

89. Teich, M. C.: Homodyne Detection of Infrared Radiation from a Moving Diffuse Target. Proceedings of the IEEE, Vol. 57, No. 5, May 1969, pp. 786-792.

Abstract: Experiments have been performed in which the radiation from a CO_2 laser was coherently detected after being scattered from a moving diffuse reflector. This is generally the configuration of an infrared laser radar. The power spectral density of the heterodyne signal was measured and its width was shown to agree with the calculated value based on a theoretical model of the process. Expressions are obtained for the ratio of heterodyne signal bandwidth to heterodyne frequency for the cases of focused radiation, unfocused radiation, and for a typical radar configuration. In most cases, the heterodyne signal is found to posses a narrow-band character. The probability density of the signal envelope was also measured for a known scatterer (providing Gaussian scattered radiation) and was found to be Rayleigh distributed, as expected. The power spectral density and envelope probability distribution provide information

about a scattering medium or target which cannot be obtained from average-value measurements of the heterodyne signal-to-noise ratio. This information is useful for communication applications, infrared radar, and heterodyne spectroscopy experiments. Finally, a simple and direct method of obtaining information about the statistics of an incident radiation field (which does not involve photocounting) is discussed.

Keywords: Homodyne Detection, Laser Radar, Heterodyne Detection, Heterodyne Signal Power Spectral Density, Signal Probability Density

90. Gibbs, W. E. K. and Kellock, H. A.: Current-Dependent Decay of CO_2 00°1 Level in Pulsed CO_2-N_2 Mixtures. Physics Letters, Vol. 29A, No. 4, May 5, 1969, pp. 190-191.

Abstract: The decay rate of the upper laser level (00°1) of CO_2 in pulsed discharges in CO_2-N_2 mixtures has been found to increase with current. Rates of more than twice that expected from CO_2-N_2 collisions have been observed.

Keywords: Upper Laser Level Decay Rate, Pulsed Discharge, Decay Rate Dependence upon Current

91. Bletzinger, P. and Gascadden, A.: "Burning" in the Electron Energy Distribution by Lasing Action in the CO_2-N_2-He Discharge. Physics Letters, Vol. 29A, No. 5, May 19, 1969, pp. 265-266.

Abstract: Experimental evidence is presented for the influence of lasing on the electron energy distribution. The changes were measured using a time-resolved Langmuir probe method.

Keywords: Plasma Electron Energy Distribution, Electron Collision Effects, Burning in of Electron Energy Distribution

92. Basov, N. G., Kompanets, I. N., Kompanets, O. N., Letokhov, V. S., and Nikitin, V. V.: Narrow Resonances in the Saturation of Absorption of SF_6 by CO_2-Laser Emission. JETP – Letters, Vol. 9, No. 10, May 20, 1969, pp. 345-347.

Abstract: The purpose of this paper is to report the observation of narrow dips inside the Doppler line of two rotational vibrational transitions of the ν_3 band of the SF_6 molecule by the method of nonlinear absorption of a quasitraveling wave of a CO_2 laser in an external low-pressure SF_6 cell. This uncovers a possibility of investigating in detail the superfine structure of the rotational-vibrational transitions of the SF_6 molecule and of obtaining extremely high stabilization of the CO_2-laser frequency.

Keywords: SF_6 Cell, CO_2 Laser Frequency Stability, SF_6 Doppler Line, Intra-Cavity Absorption Cell

93. Treacy, E. B.: Diffractive Coupling from a CO_2 Laser. Applied Optics, Vol. 8, No. 6, June 1969, pp. 1107-1109.

Abstract: Power may be coupled effectively from infrared lasers by diffractive spillover around the edge of one mirror, the mirror diameter being made so small that only the dominant mode can be supported within the laser. The beam divergence from the coupler is small.

Keywords: Diffractive Spillover Coupling, Far-Field Diffraction Pattern, Radiation Patterns

94. Hass, G. and Ramsey, J. B.: Vacuum Deposition of Dielectric and Semi-conductor Films by a CO_2 Laser. Applied Optics, Vol. 8, No. 6, June 1969, pp. 1115-1118.

Abstract: The paper describes a technique for producing thin films by high vacuum evaporation with a CO_2 laser of continuous emission at 10.6 micrometers. It is shown that at this wavelength many dielectrics are highly absorbing and that several semiconductors become sufficiently absorbing at elevated temperatures to allow their evaporation by intense radiation. The arrangement used for focusing the laser beam on the evaporant is described. The optical properties of films of SiO, SiO_2, MgF_2, Al_2MgO_4, and Te produced by the CO_2 laser evaporation technique are discussed. It is demonstrated that SiO_2 films prepared by this technique are undecomposed and non-absorbing in the uv. The future capabilities and the unique advantages of this technique for producing extremely clean films under ultrahigh vacuum conditions are outlined.

Keywords: Vacuum Deposition of Films, Deposition of Dielectric Films

95. Kikuchi, B., Nakayama, N., Misugi, T., Yamaoka, T., and Ueda, Y.: CO_2 Gas Laser. Fujitsu Scientific and Technical Journal, Vol. 5, No. 2, June 1969, pp. 117-137.

Abstract: This paper describes the results of experiments on CO_2 gas lasers. The output power and gain of a CO_2 laser can be increased by adding N_2 and He gases.

From a practical point of view, the oscillating region and the point of maximum output power were observed for CO_2-N_2 and CO_2-He mixtures and the various mixing ratios. The dependency of output power on the discharge tube diameter, coupling

hole diameter, and discharge current density were also investigated.

Keywords: Gain, Aperature (Hole) Coupling, Parameter Study, Current Modulation, Q-Switching (Rotating Mirror), Second Harmonic Generation, Effect of Tube Diameter

96. Christensen, C. P., Freed, C., and Haus, H. A.: Gain Saturation and Diffusion in CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 6, June 1969, pp. 276-283.

Abstract: The effect of rotational-vibrational relaxation and molecular diffusion on the saturation parameter of the CO_2 laser is investigated experimentally. A summary is presented of how the theory of a two-level system can be extended to a multi-level laser system like the CO_2 laser. Published experimental results for the rate of relaxation of the upper levels are such as to suggest that diffusion effects can play an important role in laser beams with radii of less than a few millimeters.

For experimental verification of the diffusion hypothesis, the gain of a sealed CO_2 amplifier is measured as a function of input power for four different beam radii. The equivalent saturation parameter derived from these measurements decreases monotonically from 97 to 25 W/cm^2 as the average input beam radius increases from 0.9 to 2.5 mm in the 9-mm-radius discharge tube of the amplifier.

Keywords: Gain Saturation, Diffusion Effects, Gain Coefficient, Saturation Parameter, Small-Signal Gain

97. Smith, D. C.: Q-Switched CO_2 Laser. IEEE Journal of Quantum Electronics, Vol. 5, No. 6, June 1969, pp. 291-292.

Abstract: Experimental studies of a rotating-mirror Q-switched CO_2 laser have been undertaken to obtain high peak powers at the 10.6-micrometer wavelength. The Q-switched pulse has a temporal structure consisting of two intensity peaks and is similar to the temporal behavior of a slow Q-switched CO_2 laser. Based on the gas pressure dependence it appears that the pulse structure and duration are influenced by collision-induced relaxations of the laser medium. Using an oscillator-amplifier system peak powers of 120 KW with pulse-widths of 200 ns have been obtained.

Keywords: Q-Switching (Rotating Mirror), Pulse Rate, Pulse Width Dependence upon Pressure

98. Bleekrode, R.: Near-Infrared Spontaneous Emission Spectra of High-Power CO_2 Lasers. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 6, June 1969, pp. 297-298.

Abstract: The purpose of this correspondence is to present information on the spontaneous emission which can be observed between 5000 and 9000 Å from high-power CO_2 lasers.

Keywords: Emission between 5000 and 9000 Å, Near-Infrared Emission

99. Kan, T., Powell, H. T., and Wolga, G. J.: Observation of the Central Tuning Dip in N_2O and CO_2 Molecular Lasers. IEEE Journal of Quantum Electronics, Vol. QE-5, No. 6, June 1969, pp. 299-300.

Abstract: The authors report the first observation of the central tuning dip (Lamb dip) on individual rotation-vibration transitions of the N_2O-N_2 molecular laser as well as observation of the effect in the CO_2-N_2 laser. They also demonstrate that a frequency discriminant can be generated from the tuning dip that is much sharper than one obtained from a similar laser operating at higher pressure.

Keywords: Lamb Dip, Frequency Discriminant, Central Tuning Dip

100. Chan, F. T. and Tang, C. L.: Rotational Transition of CO_2 Molecule by Collisions. Journal of Applied Physics, Vol. 40, No. 7, June 1969, pp. 2806-2816.

Abstract: The quantum-mechanical method of distorted waves for calculating the rotational relaxation rates in H_2 as developed by Brout is used here to calculate the relaxation time for the $\Delta J = \pm 2$ rotational transitions of linear polyatomic CO_2 by taking into account the higher partial wave contributions. The intermolecular potential used consists of a spherical part and a nonspherical part with a constant parameter to characterize the deviation of the potential from spherical symmetry. The results obtained indicate that the collision number Z (and hence the relaxation time τ) is a monotonically decreasing function of the temperature T for a given J and is a monotonically increasing function of J for a given T. Except for small values of J, Z and τ for a given T are both approximately proportional to $\exp(aJ)$, where a is a constant. Detailed numerical results are also obtained and compared with known experimental results. It is shown that the method used here is not valid when the temperature is too high or whenever Z becomes to close to 1.

Keywords: Rotational Relaxation Time, Collision Number, CO_2 Intermolecular Potential

101. McKnight, W. B.: Excitation Mechanisms in Pulsed CO_2 Lasers. Journal of Applied Physics, Vol. 40, No. 7, June 1969, pp. 2810-2816.

Abstract: Experimental studies were carried out on laser systems to investigate the excitation mechanisms of the upper laser level $(00°1)$ of carbon dioxide in an electrical discharge, and the parts played by helium and nitrogen in mixed systems. Used as constituent gases were carbon dioxide, carbon dioxide-nitrogen, and carbon dioxide-helium. Pulsed electrical excitation was used with an arrangement for varying the time delay between the discharge pulse and the alignment of a Q-switch mirror. The upper-level-to-ground radiation was observed from the side of the tube to study the behavior or the upper laser level following the current pulse and when the upper level is suddenly decreased by the Q-switch. It is concluded that the primary excitation mechanism is electron impact for pure carbon dioxide. Nitrogen is shown to contribute by acting as a storage mechanism for energy prior to resonant transfer, and a value of 1.6×10^4 $sec^{-1}Torr^{-1}$ was obtained for the rate constant of the N_2-CO_2 vibrational energy transfer process. Helium was found to contribute to increased output primarily through causing a favorable shift in electron temperature.

Keywords: Pulsed Excitation, Vibrational Energy Transfer, CO_2 Dissociation, Q-Switching (Rotating Mirror), Excitation Rates

102. Weil, R.: Interference of 10.6μ Coherent Radiation in a 5-cm Long Gallium Arsenide Parallelepiped. Journal of Applied Physics, Vol. 40, No. 7, June 1969, pp. 2857-2859.

Abstract: An experiment was performed to show that the coherence of a laser beam can be maintained over a 5-cm path in a GaAs parallelpiped. The temperature coefficient of the refractive index was measured from the temperature dependence of the intensity of radiation transmitted through the sample. The value of this coefficient was found to be $(5.64 \pm 0.28) \times 10^{-5}$ $(°C)^{-1}$ for semi-insulating GaAs at room temperature and 10.6-micrometer wavelength. The absorption coefficient of the material was measured calorimetrically and found to be 0.012 ± 0.002 cm^{-1}.

Keywords: Beam Coherence in GaAs, GaAs Parameter Study, GaAs Absorption Coefficient

103. Fein, M. E., Verdeyen, J. T., and Cherrington, B. E.: A Thermally Pumped CO_2 Laser. Applied Physics Letter, Vol. 14, No. 11, June 1 1969, pp. 337-340.

Abstract: Power of 20 mW and gain of 11% have been obtained by using thermally excited nitrogen to pump a flowing-gas carbon dioxide laser. One immediate use of this new pumping technique is the study of molecular laser physics in a simplified environment; the thermal laser is essentially free of chemical and charged-particle effects.
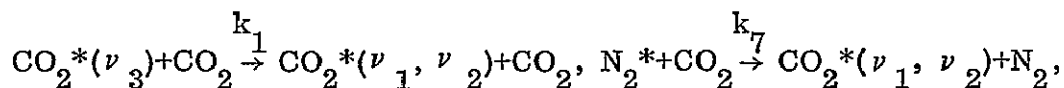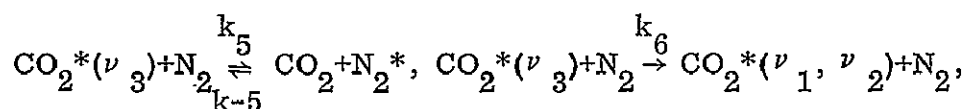
NOTE

Text Corrections appear in Applied Physics Letter, Vol. 15, No. 4, August 15, 1969, p. 128.

104. Rosser, Jr., W. A., Wood, A. D., and Gerry, E. T.: Deactivation of Vibrationally Excited Carbon Dioxide (ν_3) by Collisions with Carbon Dioxide or with Nitrogen. Journal of Chemical Physics, Vol. 50, No. 11, June 1, 1969, pp. 4996-5008.

Abstract: The rate constants associated with the deactivation of vibrationally excited $CO_2{}^*(\nu_3)$ by collision with either CO_2 or N_2 have been experimentally determined from 300°-1000° K by a laser fluorescence method. The reactions investigated were

$$CO_2{}^*(\nu_3)+N_2 \underset{k_{-5}}{\overset{k_5}{\rightleftharpoons}} CO_2+N_2{}^*, \quad CO_2{}^*(\nu_3)+N_2 \overset{k_6}{\to} CO_2{}^*(\nu_1, \nu_2)+N_2,$$

$$CO_2{}^*(\nu_3)+CO_2 \overset{k_1}{\to} CO_2{}^*(\nu_1, \nu_2)+CO_2, \quad N_2{}^*+CO_2 \overset{k_7}{\to} CO_2{}^*(\nu_1, \nu_2)+N_2,$$

where the asterisk denotes a vibrationally excited molecule, and the quantities in parentheses represent the specific excited modes of CO_2. The rate constant k_5 varies with temperature T (°K) as $8.60 \times 10^7/T^{3/2}$ torr$^{-1} \cdot$ sec^{-1}. From 400°-1000°K the rate constant k_1 (per torr$^{-1} \cdot$ second^{-1}) varies with temperature as

$$\log_{10}k_1 = A - BT^{-1/3}$$

with A=6.79 and B=30.8. From 300°-400° K the measured values of k_1 are greater than those corresponding to the above relation. The rate constant k_6 increases from a value of 110 $torr^{-1} \cdot sec^{-1}$ at room temperature to a value of 2700 $torr^{-1} \cdot sec^{-1}$ at 1000°K, but the variation of k_6 with temperature cannot be simply expressed. The rate constant k_7 was found to be negligibly small compared to the other rate constants.

Keywords: De-excitation of CO_2, Rate Constant Determination, Depopulation of 001 Mode, Additives (He, O_2), Side-Light Emission

105. Andrick, A., Danner, D., and Ehrhardt, H.: Vibrational Excitation of CO_2 by Dipole Interaction with Slow Electrons. Physics Letters, Vol. 29A, No. 6, June 2, 1969, pp. 346-347.

Abstract: The observed vibrational excitation of molecules in low energy electron scattering has been attributed in recent years exclusively to the temporary formation of a negative ion. Measurements on CO_2 show that dipole interaction can also give rise to strong vibrational excitation.

Keywords: CO_2 Dipole Interaction, Excitation by Electron Scattering

106. Rabinowitz, P., Keller, R., and LaTourrette, J. T.: "Lamb Dip" Spectroscopy Applied to SF_6. Applied Physics Letters, Vol. 14, No. 12, June 15, 1969, pp. 376-378.

Abstract: Line centers of a number of previously unresolved SF_6 transitions of the fundamental ν_3 band have been observed and their frequencies have been determined relative to the P-branch transitions of the CO_2 10.6-micrometer laser. Measurements of dip widths at small saturation levels yielded a determination of the SF_6-SF_6 cross section for phase interruption. Observation of a multiplicity of absorption line centers over the tuning range of the P(20) laser transition, several well within one SF_6 Doppler width of 29 MHz, verifies the complex nature of the P(20) line absorption found by other workers.

Keywords: "Lamb Dip" Spectroscopy, Spectroscopy, SF_6 Absorber, Absorption Resonance in SF_6

107. Shimizu, F.: Absorption of CO_2 Laser Lines by SF_6. Applied Physics Letters, Vol. 14, No. 12, June 15, 1969, pp. 378-380.

Abstract: Absorption of CO_2 laser lines by SF_6 was studied by several methods for various P laser lines of the 00°1-10°0 band. It is concluded that the absorption of the P(20) line is mainly due to the several SF_6 lines with J values between 50 and 80.

Keywords: SF_6 Absorber, SF_6 Absorption Coefficient, Laser Line Centers

4. ALPHABETICAL LISTING OF AUTHORS

The following section is an alphabetical listing of the authors whose publications are listed in this report. The numbers to the right of the author's name are the chronological reference numbers assigned in the previous section.

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5.   ALPHABETICAL LISTING OF KEYWORDS OR PHRASES

This section contains an alphabetical listing of the keywords or phrases which are listed after each reference in section 2 of this report. The numbers to the right of the keyword or phrase are the chronological reference numbers assigned in section 2.

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